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HOLOGRAPHIC FLOW VISUALIZATION AT THE LANGLEY CF_4 TUNNEL

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SUMMARY

A holographic flow visualization system has been used to obtain shadowgraph, schlieren, and interferograms of the flow field at Langley's hypersonic (Mach 6) CF_4 tunnel. The dual hologram technique which was used in this study makes it possible to vary focusing, knife-edge position, and the orientation and spacing of the interference fringes after a tunnel run. The experimental arrangement necessary to produce high quality interferograms is discussed. Typical shadowgraphs, schlieren pictures, and interferograms are presented.

INTRODUCTION

During the past decade holographic interferometry has largely superseded the classical Mach-Zehnder interferometer for measuring density in aerodynamic research facilities. Holographic interferometry is a nonintrusive optical technique which offers the additional capability over conventional interferometry of, in effect, recording for later reconstruction the flow and no-flow optical fields. It is the interference between these two optical fields which yields fringe data necessary for density calculations.

Several variations of holographic interferometry exist. The first method to be applied to wind-tunnel testing was the double pulse method (refs. 1, 2). In the double pulse method both the flow and no-flow recordings are made on the same photographic plate. A disadvantage of the double pulse technique is the inability to adjust the fringe orientation or spacing after a tunnel run. This adjustment of fringe orientation and spacing is sometimes desirable to aid in analyzing the fringe shift data.

A second variation of holographic interferometry is to record only the no-flow optical field (ref. 3). The reconstructed no-flow field is then made to interfere with the real-time flow optical field. Although this technique has the advantage of continuous time resolved data as often required for shock or expansion tubes (ref. 4), there is still the inability to adjust fringe spacing and orientation after data is taken.

Still another variation is the recording of the flow and no-flow fields on separate photographic plates (ref. 5). A tilt or translation can be introduced between the reconstruction of the flow and no-flow fields to vary the fringe orientation and spacing after the fields are recorded. This technique, sometimes called dual holography, has been demonstrated to be a very useful tool in aerodynamic research (ref. 6). It is the application of this technique to Langley's CF_4 tunnel, based largely on the work from reference 6, which is presented here. The main purpose of this work was to gain familiarity with the technique and determine its applicability to routine large-scale tunnels for both flow visualization and quantitative density measurements. A necessary first phase was the obtaining of repeatable, high quality interferograms. No attempt is made to discuss three dimensional data analysis schemes.

FACILITY DESCRIPTION

The hypersonic CF_4 tunnel is a blow-down type facility with a maximum run time of 60 seconds. The test gas used is CF_4 (Freon 14). The purpose of using CF_4 is to better simulate the real-gas effects on blunt bodies (ref. 7). The system consists of a high-pressure storage field, pressure regulator, lead bath heaters, nozzle, test section, vacuum spheres, and CF_4 reclaimer (fig. 1).

The bottle field consists of six storage bottles ($0.85\ m^3$ each) which store the gas at pressures up to $3.4 \times 10^7\ N/m^2$ (5000 psia). The lead bath heaters consist of two tanks which contain 9.1×10^3 kg of molten lead each. A series of stainless-steel tubes are immersed in molten lead which carries the CF_4 gas. The lead is heated by means of thermostatically controlled electric heaters which are also immersed in the molten lead. The temperature range over which the lead bath heaters will operate is 645 K to 920 K. The piping between the lead bath heater and the settling chamber are also heated by means of electric strip heaters.

The nozzle is an axisymmetric-contoured nozzle which was designed for a Mach number of 6. The nozzle will operate over a pressure range of from $6.9 \times 10^6 N/m^2$ to $1.7 \times 10^7\ N/m^2$ (1000 psia to 2500 psia). The nozzle exit is 0.5 m in diameter and has a test core of approximately 0.38 m.

The test section is a 1.5 m diameter tank approximately 1.8 m long with observation windows on two sides and on top. The test section contains a model insertion mechanism which inserts and retracts the model from the test stream during the run. This mechanism has an angle-of-attack range of from -15^o to $+15^o$.

The vacuum system consists of three spheres with a total volume of $2.3 \times 10^3\ m^3$ with vacuum pumps capable of pumping the spheres down to a pressure of $67\ N/m^2$ (0.5 mm Hg).

The tunnel is operated by setting the desired run pressure on the regulator, opening the test section to the vacuum spheres, and opening the main isolation valve. When flow is established (approximately 2 sec) the model is inserted into the test stream for the desired run time and then retracted. The tunnel is shut down by closing the main isolation valve.

Instrumentation is available to handle 45 channels of strain gage type transducers or 42 channels of thermocouples. The data acquisition system is capable of recording 45 channels of data on magnetic tape. The bit rate is 400 bits per second. An additional 50 channels of data can be recorded on strip chart type recorders.

The nozzle has been operated over a pressure range from 6.9×10^6 N/m^2 to 1.7×10^7 N/m^2 (1000 psia to 2500 psia) and a temperature range from 645 K to 750 K. The Mach number varies from 6.08 to 6.4, depending on temperature and pressure. The Reynolds number range over which the tunnel can operate is 55,000 to 183,000 per meter. Total pressure behind the normal shock varies from approximately 6.9×10^3 N/m^2 to 20×10^3 N/m^2 (1.0 psia to 3.0 psia). Models as large as 0.13 m in diameter with cone angles up to 140° have been tested in the tunnel.

HOLOGRAPHIC SYSTEM

The holographic system (figs. 2 and 3) follows very closely that of reference 6. The laser used to record the holograms was a commercial pulsed ruby laser. A Pockels cell Q-switch produced laser pulses of about 50 millijoules with a half-width of about 20 nanoseconds. An intracavity 2 mm aperture was used to restrict lasing to the fundamental transverse mode, which insured good spatial coherence. An intracavity etalon reduced the laser spectral linewidth, thus increasing the coherence length (temporal coherence) of the emitted radiation. The output of the laser was horizontally linearly polarized.

A 6 milliwatt He-Ne alinement laser was positioned behind the ruby laser on precision rotation and translation stages to facilitate accurate alinement of the interferometer. In figure 4 shearing interferograms are presented to compare the ruby and He-Ne reference beams. The difference in tilt between the fringes of the two interferograms is due to a focus shift between the ruby and He-Ne beams.

The ruby and alinement lasers were mounted on a large stationary-type tripod so that the laser beam was horizontal and crossed the center of the test section. The stability of this arrangement was evident in that realinement of the ruby laser was not necessary for several weeks at a time.

An uncoated glass wedge was used as a beam splitter to direct about 4 percent of the incident power into the scene beam and about 92 percent into the reference beam. The 1-inch dielectric coated folding mirrors for the reference beam were flat to better than 0.1 of the ruby wavelength. Reflectivity at a nominal 45° angle of incidence was about 99 percent at the ruby wavelength. Relatively simple commercially available mounts were used for fine positioning of the folding mirrors.

The commercially available spatial filter mount consisted of a pinhole movable in a plane perpendicular to the direction of propagation of the laser beam and a standard microscope objective which could be translated along the beam direction. A 45X objective and 25 micron pinhole were used for the scene beam and a 10X objective and 75 micron pinhole were used for the reference beam. The focus difference between the ruby and He-Ne alinement laser noted in figure 4 was not considered a problem since the beam waist does not change appreciably over this small distance. If necessary a focus correction could be made for the ruby beam. A low cost telescope doublet was used to collimate the reference beam after it passed through the spatial filter.

The aluminized parabolic mirrors in the scene beam were 40 cm diameter, 245 cm focal length with reflectivity greater than 85 percent at the ruby wavelength. Surface accuracy was better than 0.1 of the ruby wavelength. These mirrors were previously used at the tunnel for white-light schlieren and shadowgraph. The tunnel windows were 3 cm thick, flat to one wavelength per 30 cm, and had a slight wedge. The tunnel windows were in place for both no-flow and flow holograms.

The dual plate holder was made from plans of a unit used in reference 8. Its purpose was to move the two holograms with respect to each other in order to adjust the interferogram for the desired fringe spacing and orientation.

The holograms were recorded on both Agfa 10E75 and Kodak 120-02 photographic plates. Both types of plates have resolving powers greater than 2000 lines/mm. The Agfa plates, requiring 50 ergs/cm^2 for proper exposure by a short pulse duration ruby laser, are ten times as sensitive as the Kodak plates. The reference beam diameter was 5 cm. The scene beam diameter was slightly smaller than the reference at the intersection of the plates. Standard development procedures were used at 20^{o}C. The plates were developed together in Kodak's D-19 for 5 minutes, washed in water for 2 minutes, fixed for 4 minutes, then washed for 10 minutes and allowed to dry.

The measured diffraction efficiencies of the amplitude holograms made on photographic plates were about 0.5 percent. By overexposing the plates and then bleaching them in Kodak's chromium intensifier solution A, diffraction efficiencies could be increased by an order of magnitude or more. The plates after bleaching are semitransparent. This bleaching technique was useful initially when using the alinement laser for reconstruction. A disadvantage is the additional flair noise introduced by the bleaching process. For this reason amplitude holograms resulted in higher quality interferograms and were used for the tunnel runs.

Reconstruction was done in place using a separate 5 milliwatt He-Ne laser and similar beam expanding and collimating optics as used for recording the hologram. There was sufficient irradiance on the film plane for typical exposure times on 125 ASA film of about 0.5 seconds. The reconstruction was also bright enough to observe the fringes with the room lights off. The fringes were stable (no detectable motion by eye) so that long exposures for photographing the reconstructed interferograms were not a problem. A single element positive lens of low power was used at the sagittal focus to image the model onto the 10 x 13 cm (4 x 5 inch) film plane. Figure 5 shows an unfocused interferogram. To first order the magnification of the system is not affected by the focusing lens if the first nodal point of the focusing lens coincides with the paraxial focus. Polaroid photographs were made to check exposures and for fast data recording. The prints in this paper were made from 10 x 13 cm (4 x 5 inch) plus-x negatives.

The inital alinement of the interferometer is not difficult. The scene and reference geometrical pathlengths at the CF_4 tunnel were equal to within 5 cm. The pathlength from the ruby laser to the hologram plane was about 15 meters.

The use of a Pockels cell for Q-switching the laser necessarily results in a linearly polarized output. It is important that the plane of polarization of the reference beam is not rotated before intersecting the scene beam for hologram recording since for two linearly polarized waves which intersect the fringe visibility varies as the cosine of the angle between the planes of polarization. Hence, if the polarization vectors are orthogonal, the visibility is zero and no hologram is recorded.

RESULTS

With only the flow plate in place a focused shadowgraph is seen (assuming a focusing lens is used) (fig. 6). Now either a horizontal or vertical knife-edge can be used at either the sagittal or tangential focus, respectively, for schlieren (fig. 7). If the knife-edge is removed and the no-flow plate is put into the dual plate holder, interference fringes are observed between the reconstructed flow and no-flow optical fields. These fringes are essentially circular since upon reconstruction the no-flow optical field passes through an additional thickness of glass (the flow hologram plate). This results in a focus shift.

By a combination of translation and rotation various fringe orientation and spacings are possible. In figure 8 a case close to the infinite fringe is shown. Here the two reconstructed fields are superimposed without focus shift or rotation. If now one plate is translated vertically with respect to the other, horizontal fringes result (fig. 9). The amount of displacement determines the fringe spacing. Figure 10 represents increasing amounts of vertical displacement between the two holograms. If one of the plates is displaced horizontally in its plane from the infinite fringe case, vertical fringes are seen (fig. 11). Note that the sense of the fringe shift for a density increase is determined by whether the flow hologram is to the right or left of its infinite fringe position. A good analogy for the formation of these fringes is the interference fringes resulting from two displaced ideal point sources (ref. 9). The fringes formed throughout space are given by hyperboloids of revolution. By intersecting the surface of revolution with the observing plane, the resulting interferogram in that plane is determined.

Once the holograms are removed from the plate holders of the dual hologram positioner fringes may be obtained at a later date by insuring that the foci of the two reconstructed scene beams coincide upon reconstruction. It is possible to interchange the two plates and still observe interference fringes. These fringes are circular due to the large focus shift.

For one tunnel run a third photographic plate was placed between the two plates normally used for the dual technique. Both flow and no-flow exposures were made on this plate so that a double pulse interferogram resulted (fig. 12). With this three-plate technique it was possible to compare dual and double pulse interferograms recorded with the same laser pulses (fig. 13). The correspondence between the two interferograms demonstrates the similarity of the two techniques. The spurious interference fringes noted in figures 12 and 13 are due to multiple reflections from one plate onto another.

CONCLUSIONS

1. High quality interferograms are possible at Langley's CF_4 tunnel using the dual hologram technique.

2. Alinement and maintenance does not appear particularly difficult. The system appears feasible for use in large scale hypersonic wind tunnels.

3. The dual hologram technique is the most promising of the holographic methods for use where continuous time resolved data recording is not required.

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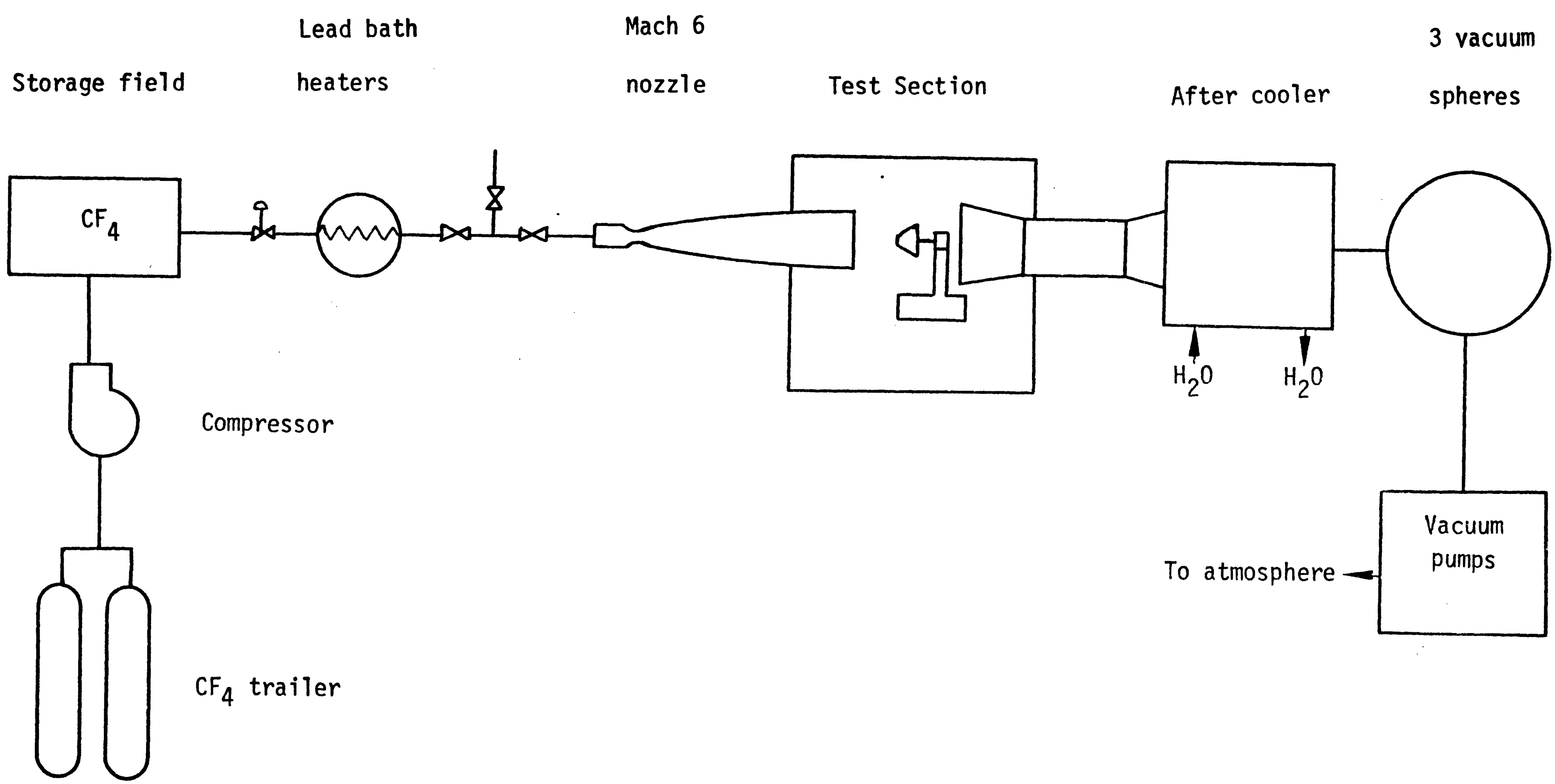


Figure 1.- Schematic of CF_4 tunnel

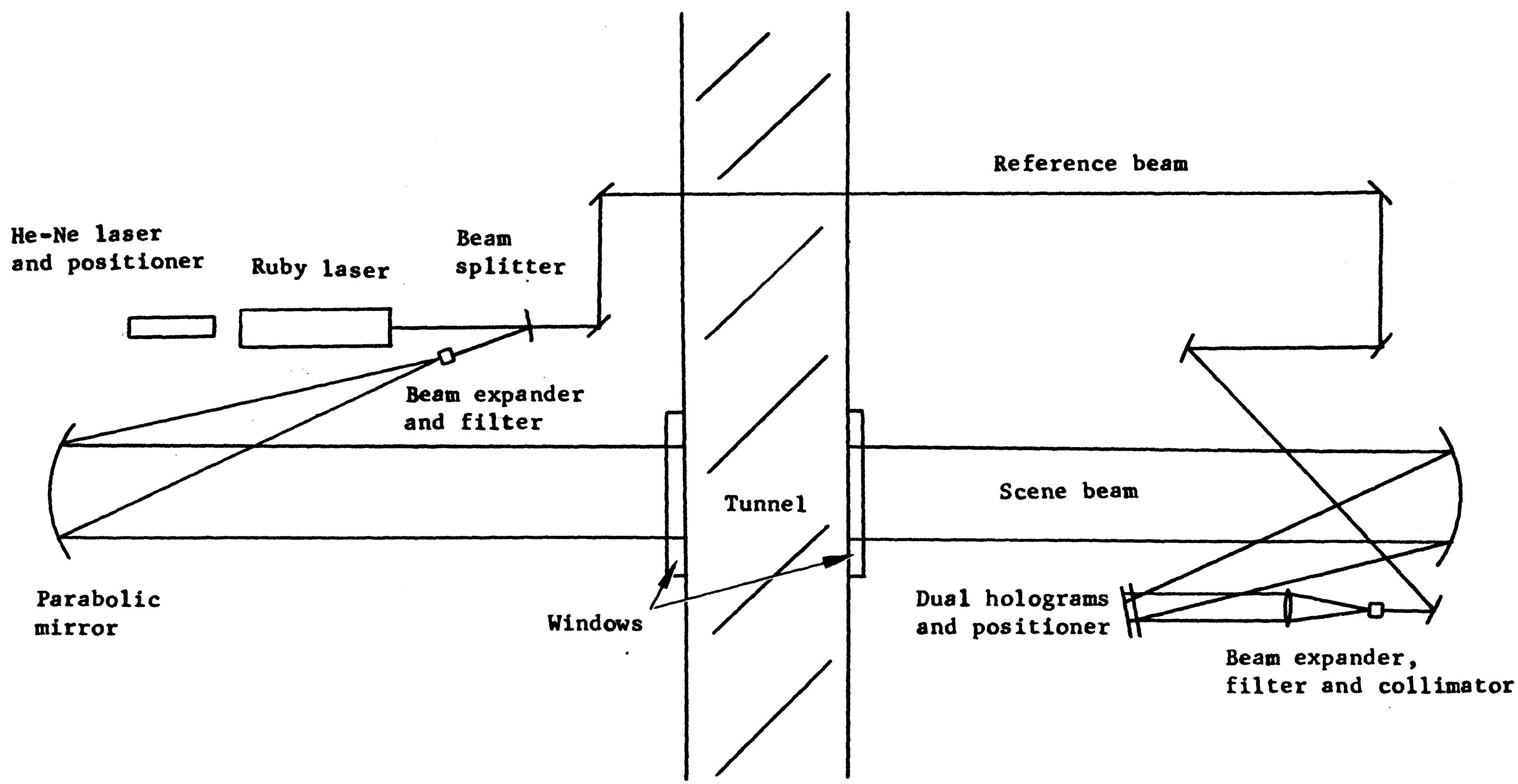
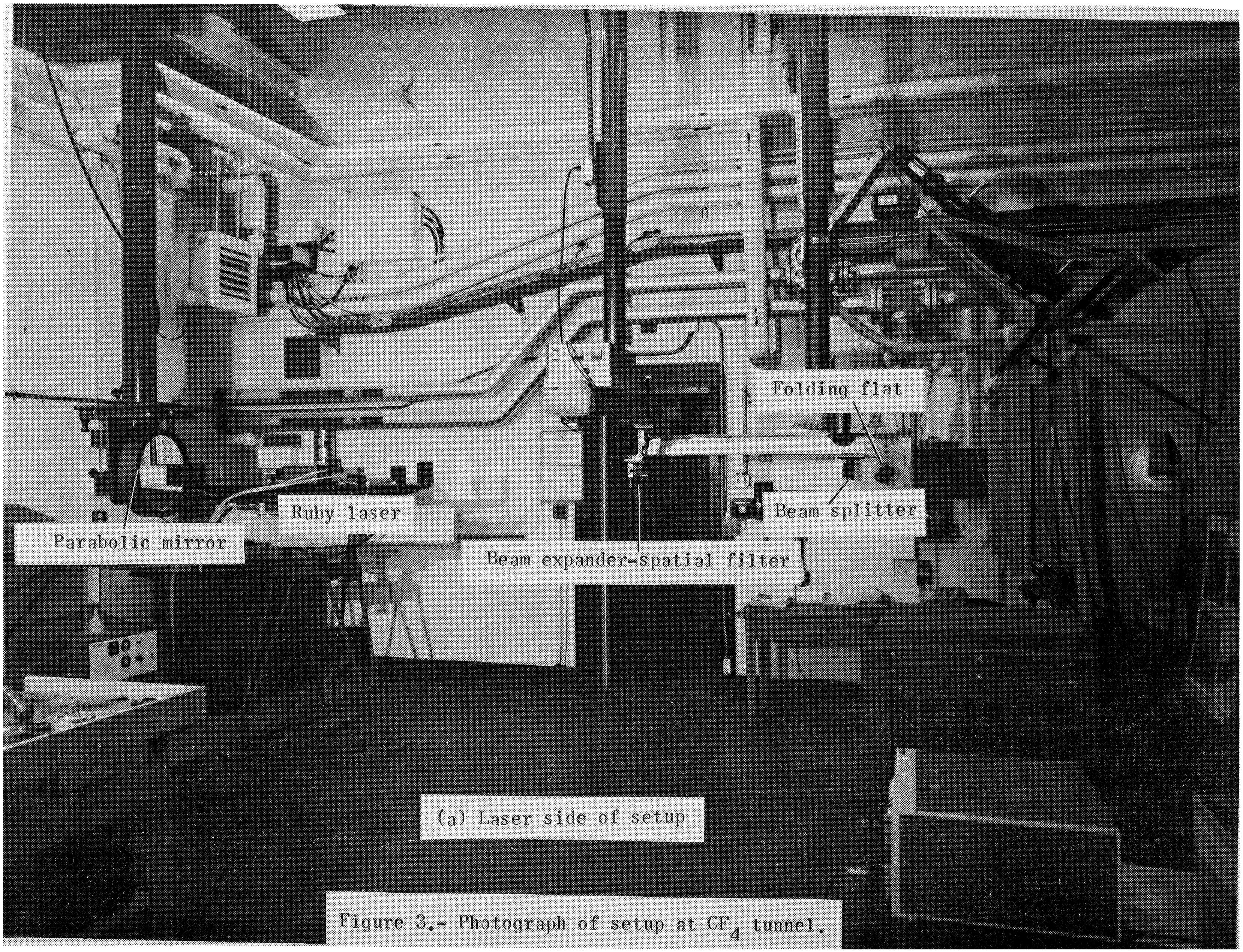
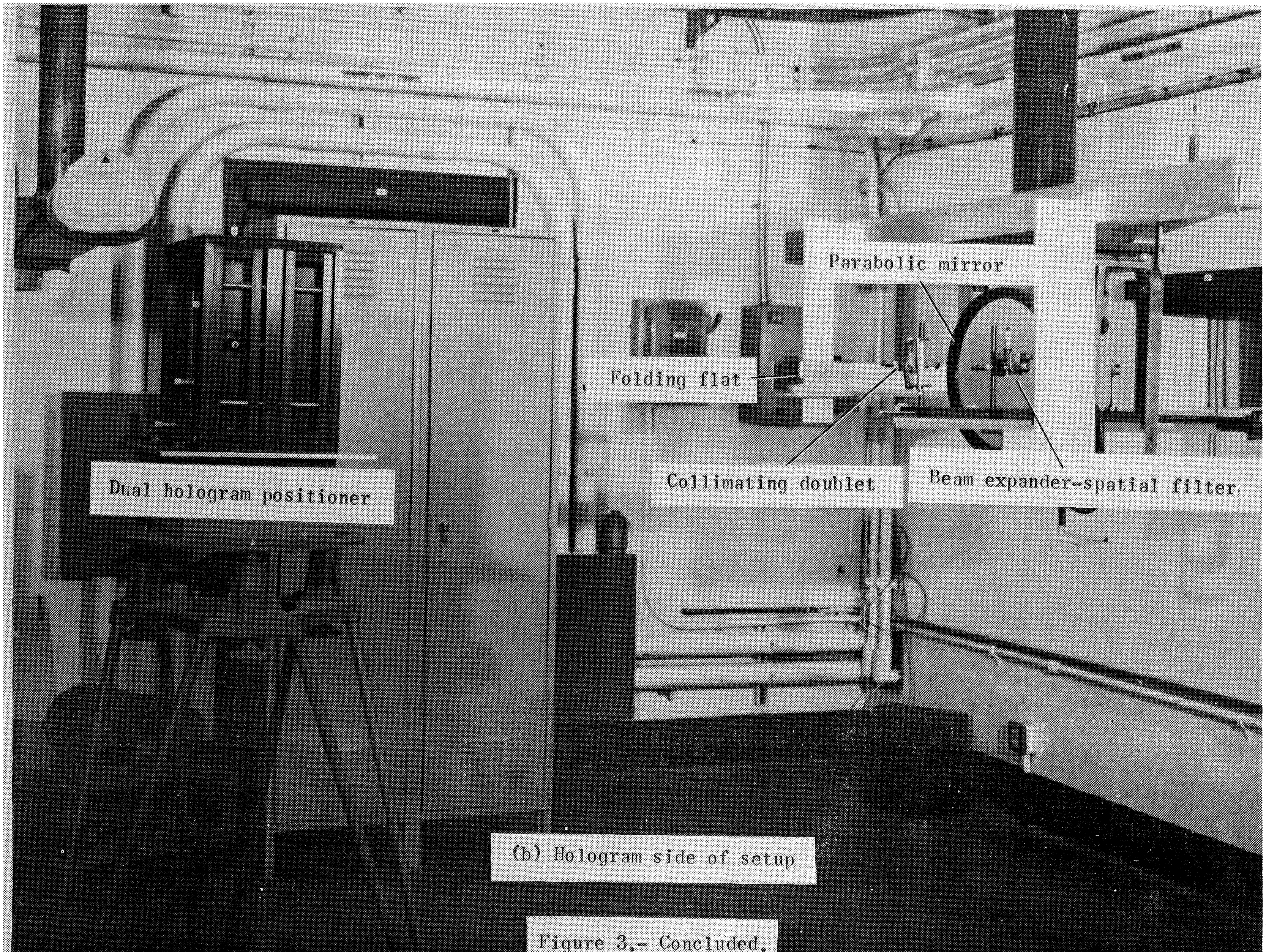


Figure 2. - Holographic system at CF_4 tunnel.



(a) Laser side of setup

Figure 3.- Photograph of setup at CF_4 tunnel.



(b) Hologram side of setup

Figure 3.- Concluded.

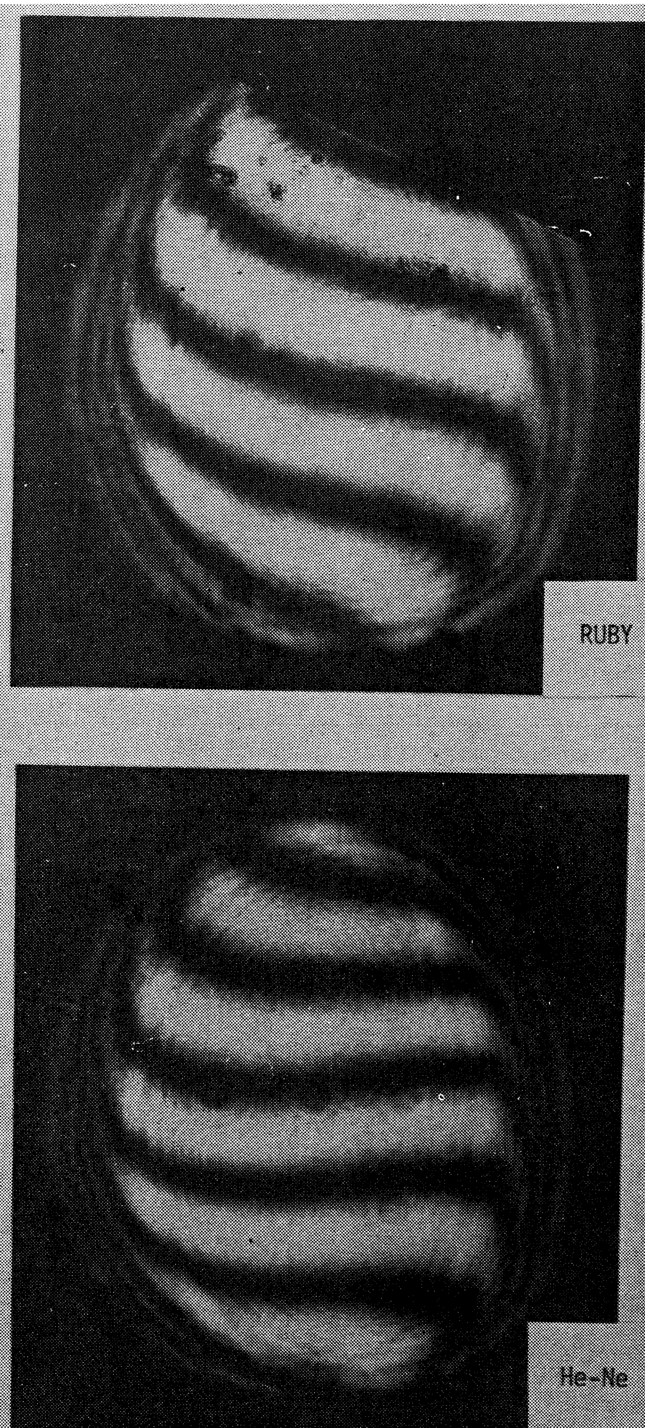


Figure 4. - Shearing interferograms of ruby and He-Ne reference beams.

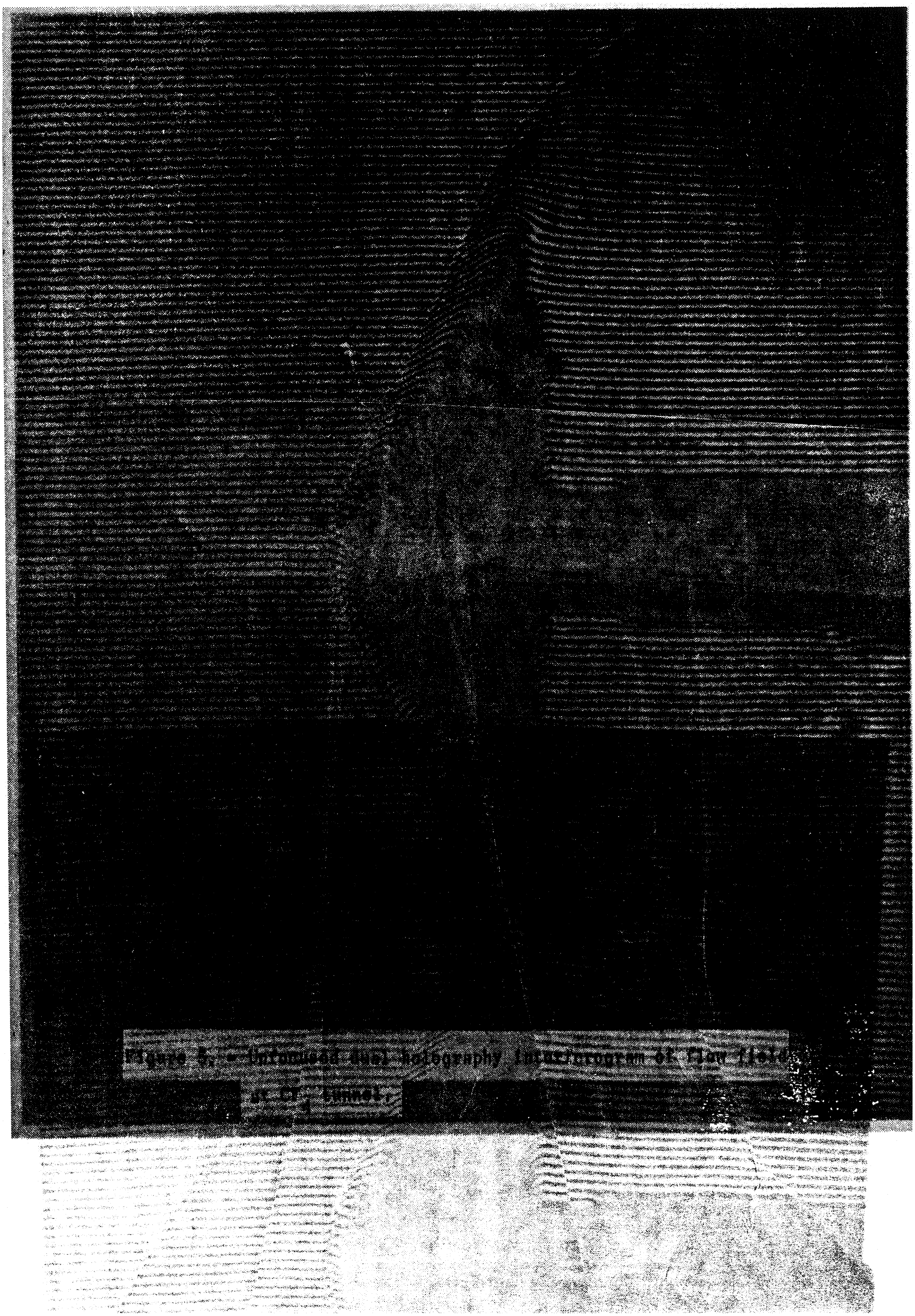


Figure 5. - Unfocused dual holography interferogram of flow field

[illegible] of [illegible] tunnel, [illegible]

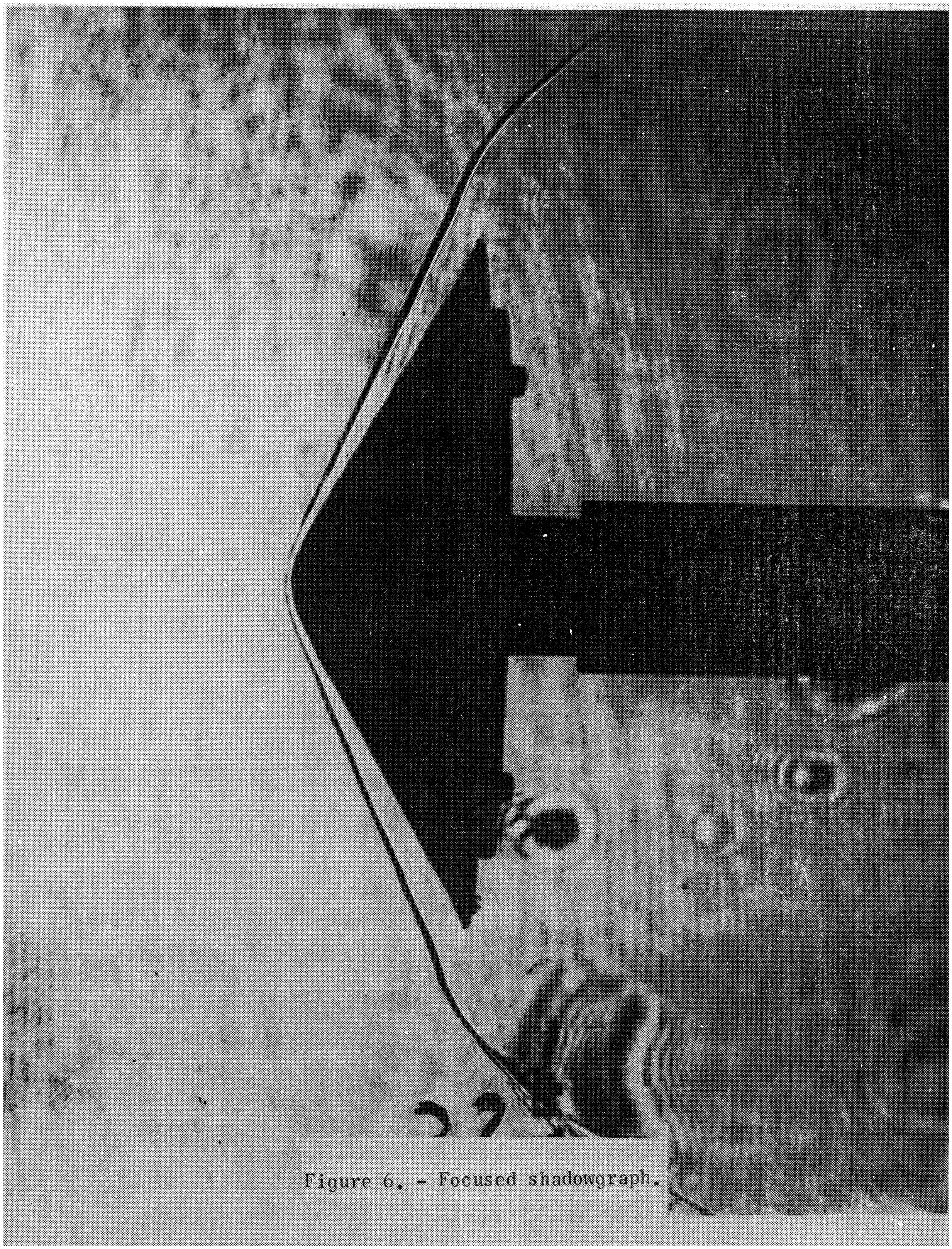


Figure 6. - Focused shadowgraph.

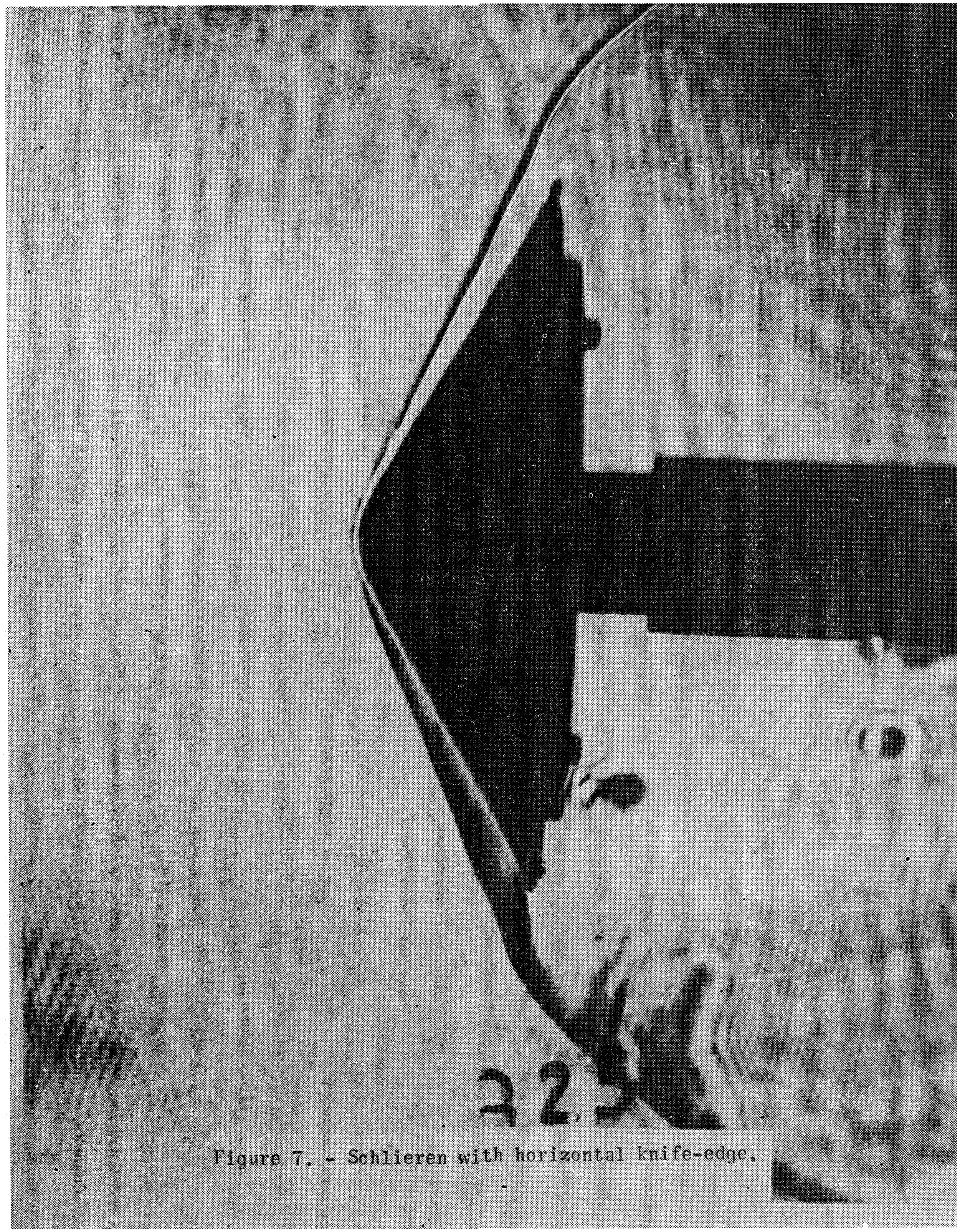


Figure 7. - Schlieren with horizontal knife-edge.

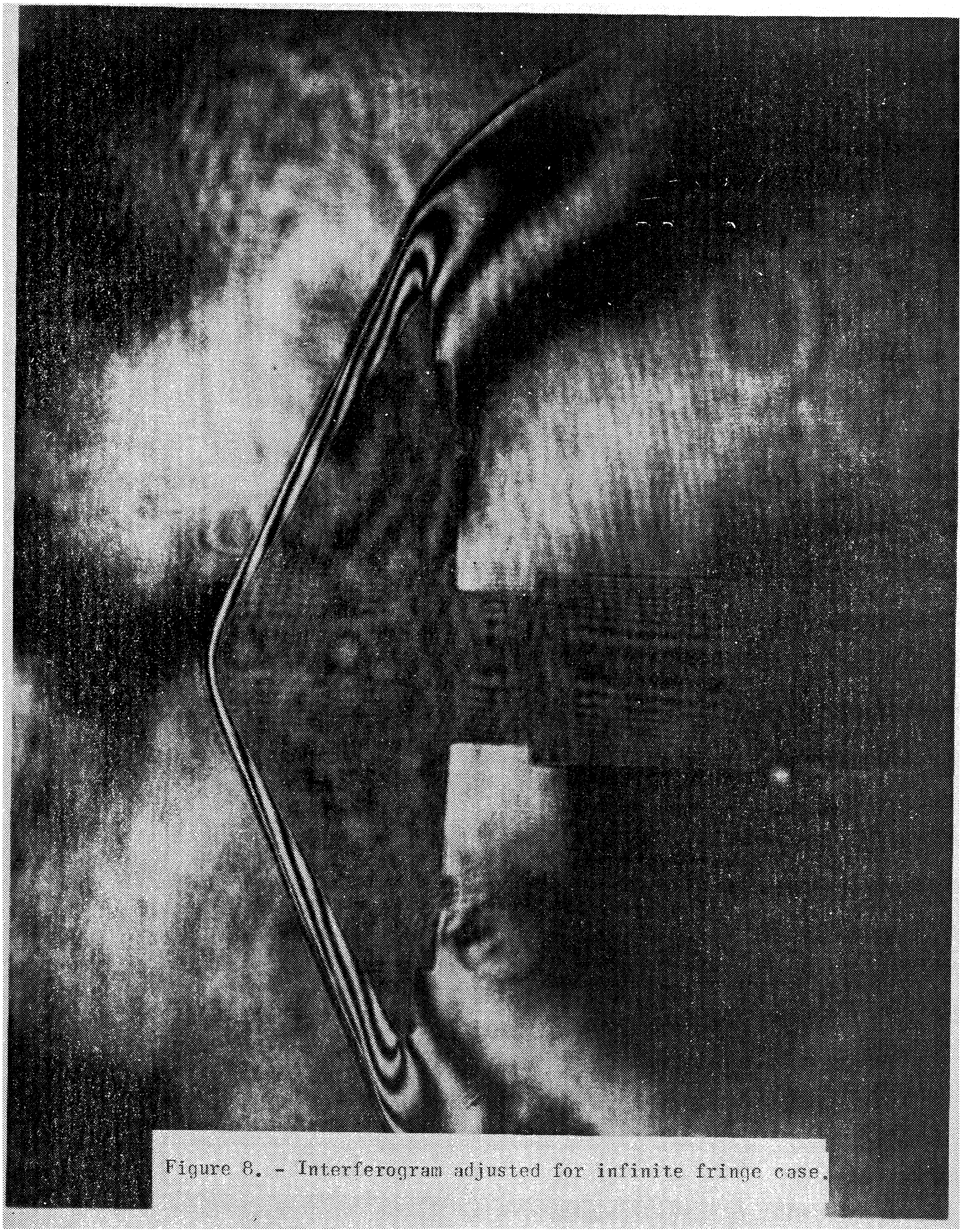


Figure 8. - Interferogram adjusted for infinite fringe case.

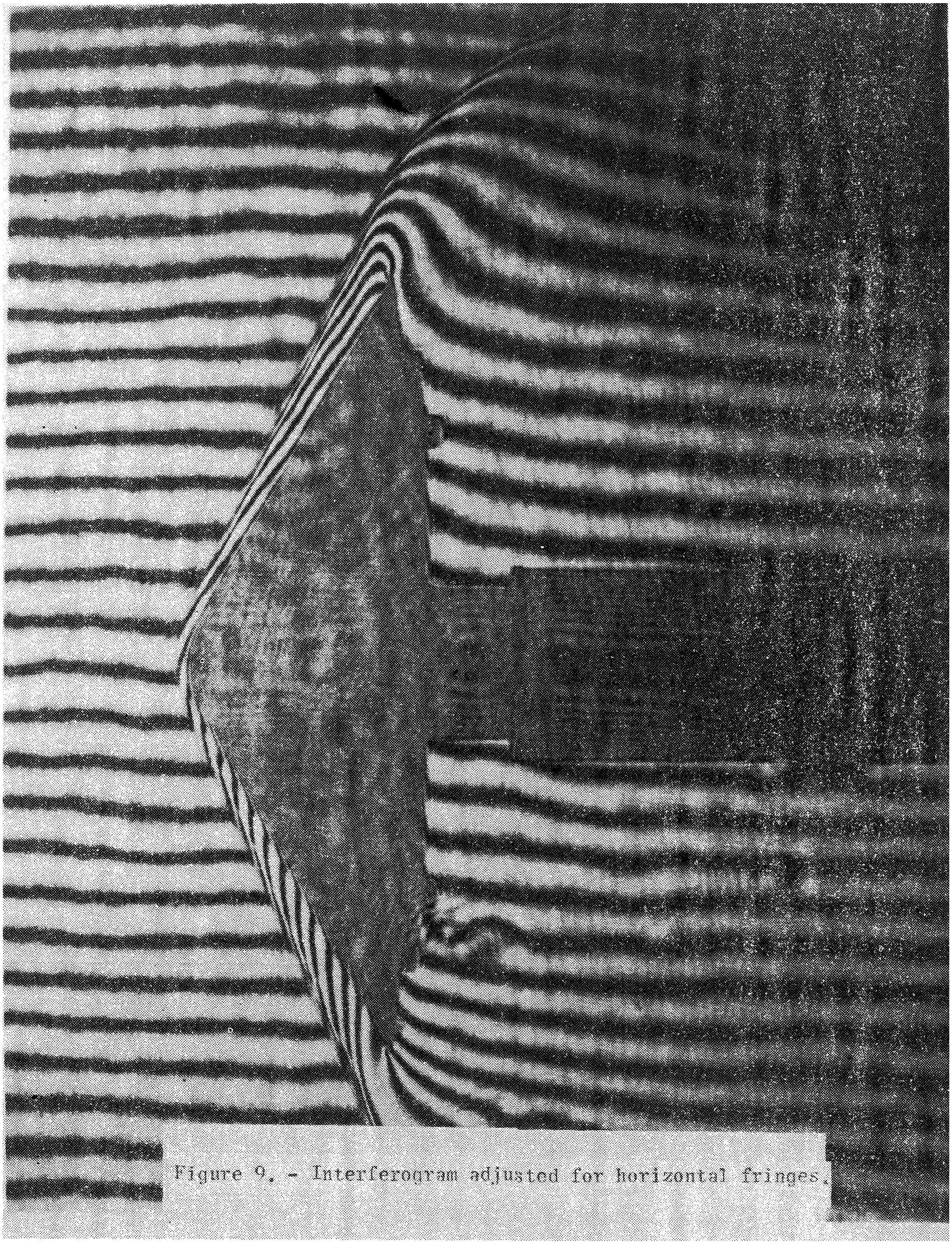


Figure 9. - Interferogram adjusted for horizontal fringes.

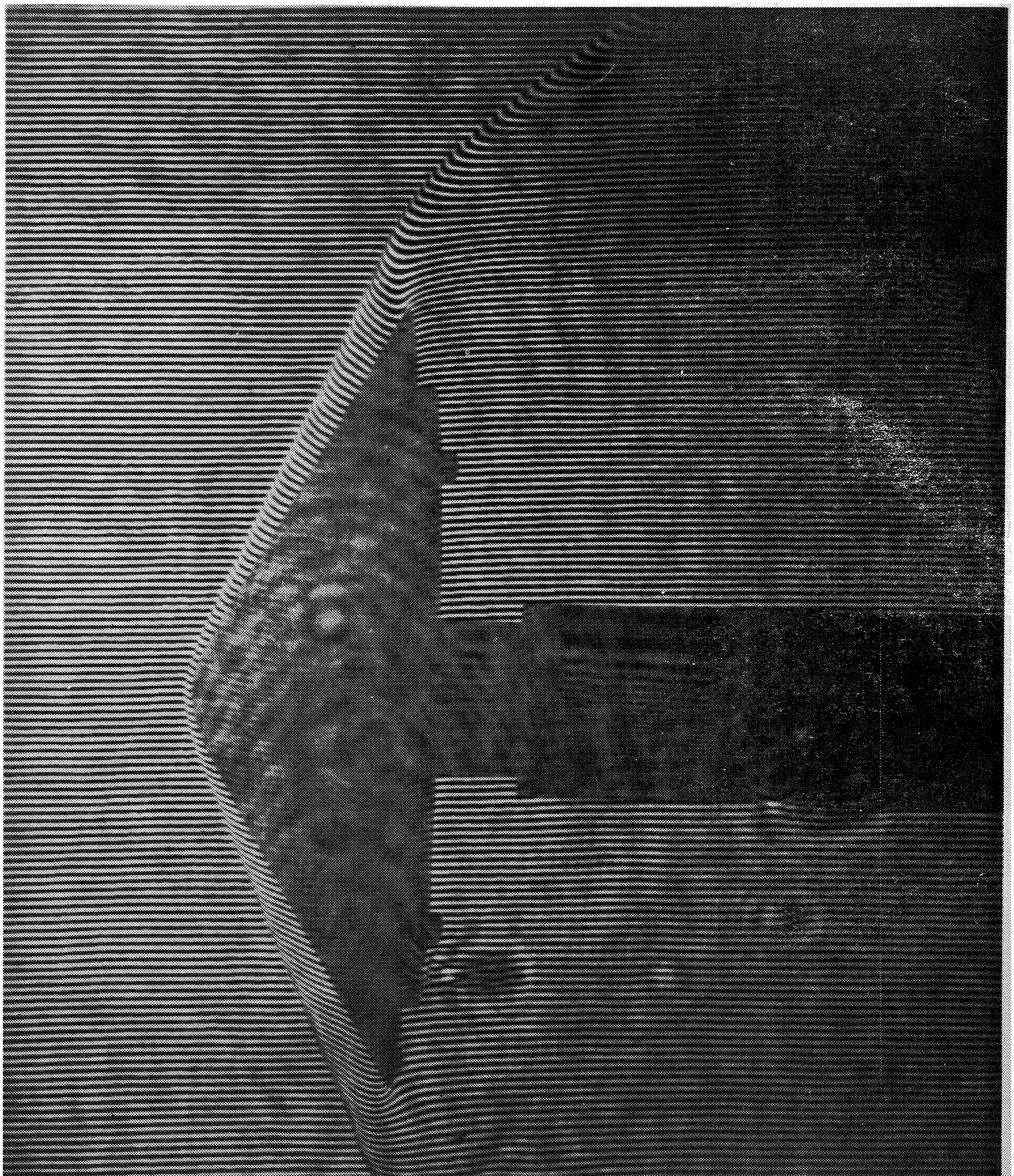


Figure 10. - Interferogram adjusted for finely spaced horizontal fringes.

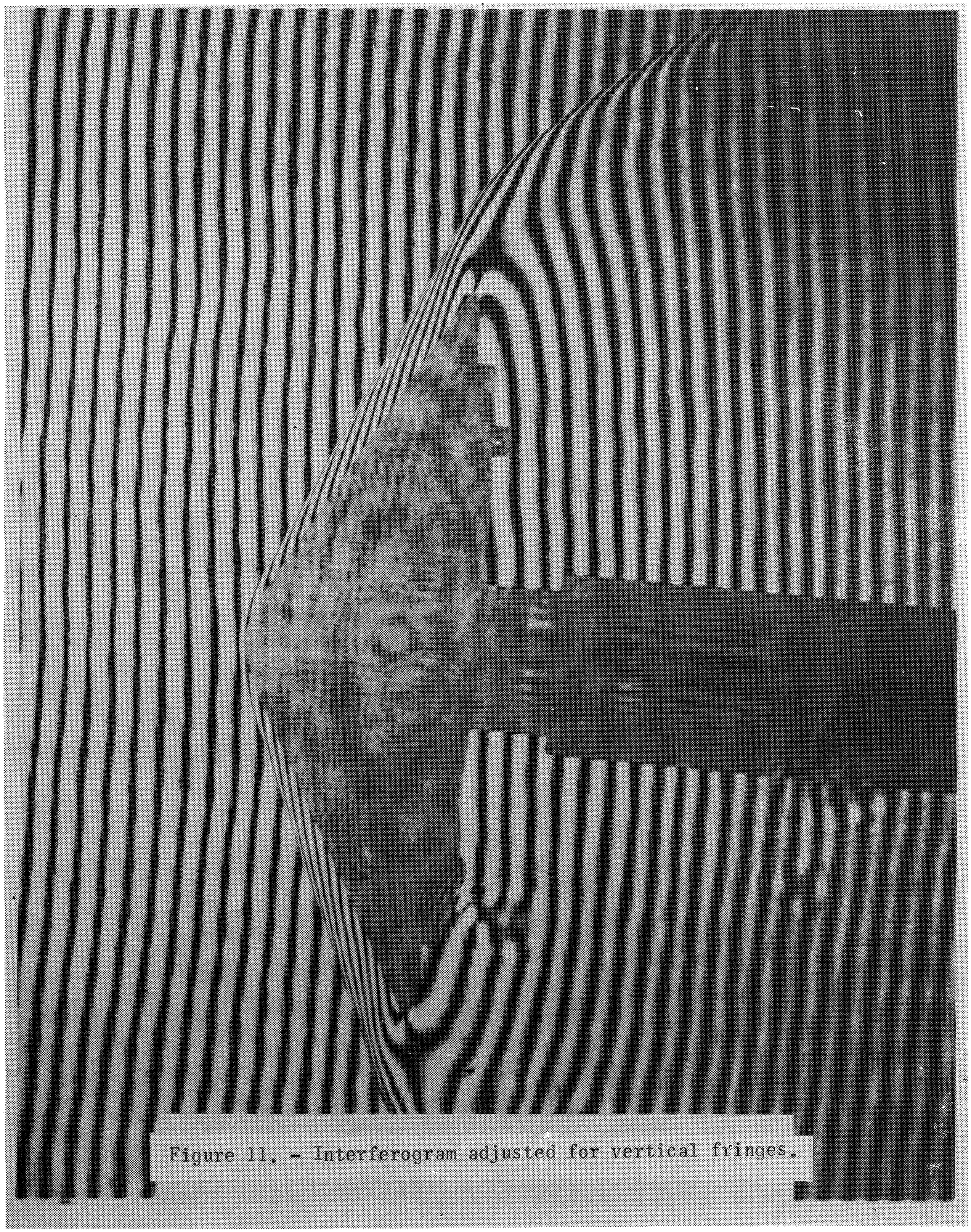


Figure 11. - Interferogram adjusted for vertical fringes.

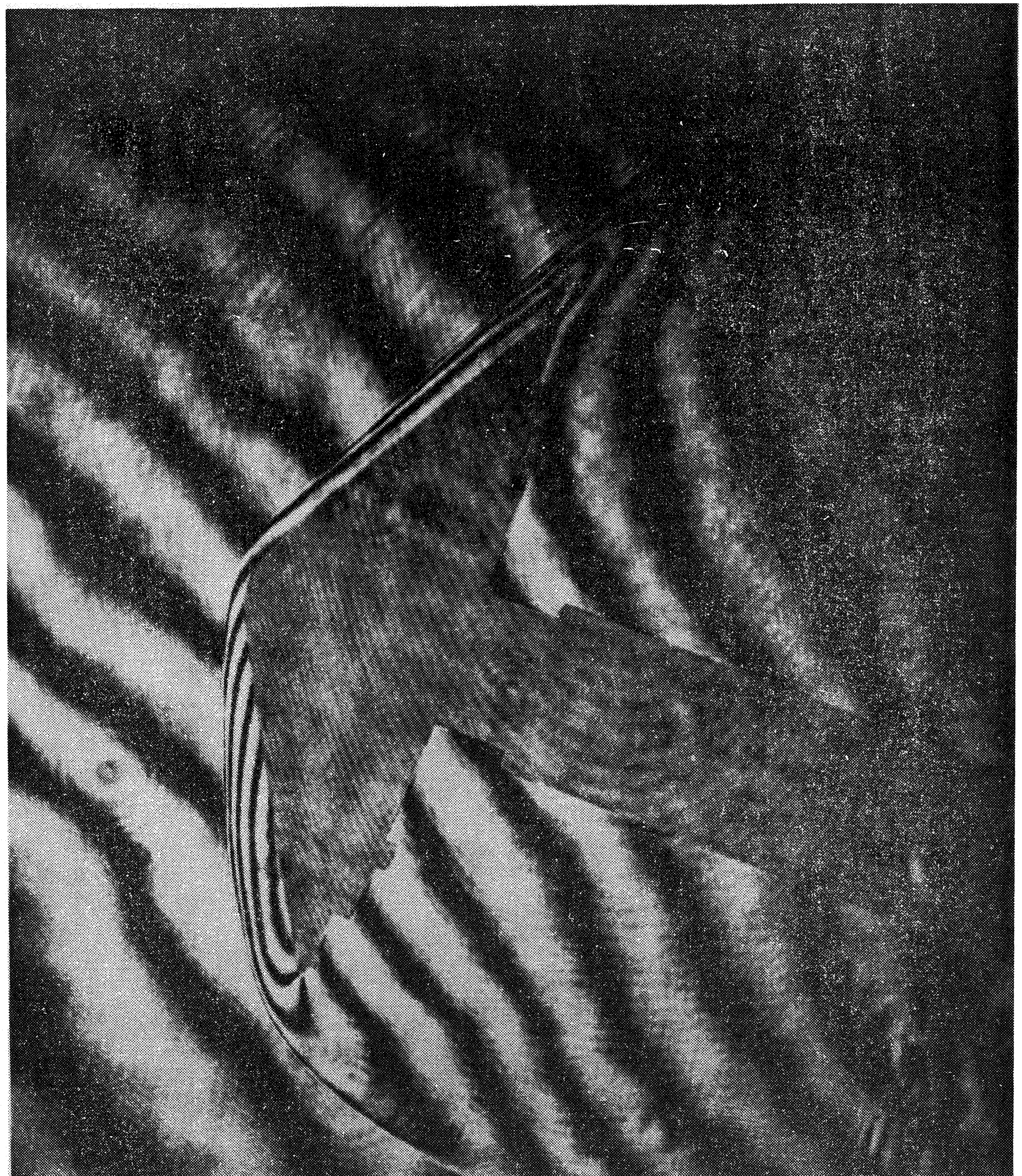


Figure 12. - Interferogram using double pulse technique (compare to figure 13).

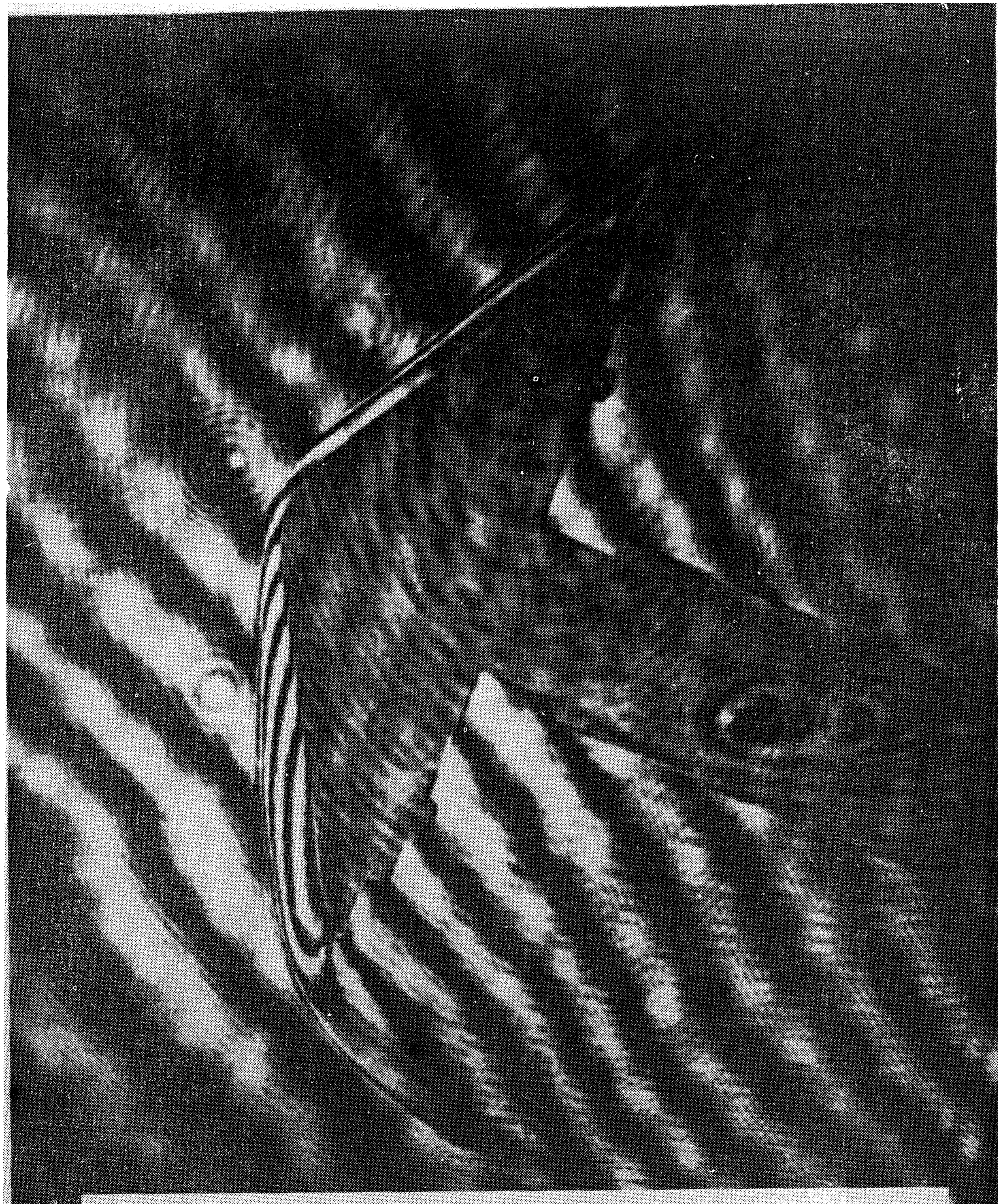


Figure 13. - Interferogram using dual holography (compare to figure 12).

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15. Supplementary Notes

16. Abstract

A holographic flow visualization system has been used to obtain shadowgraph, schlieren, and interferograms of the flow field at Langley's hypersonic (Mach 6) CF_4 tunnel. The dual hologram technique which was used in this study makes it possible to vary focusing, knife-edge position, and the orientation and spacing of the interference fringes after a tunnel run. The experimental arrangement necessary to produce high quality interferograms is discussed. Typical shadowgraphs, schlieren pictures, and interferograms are presented.

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